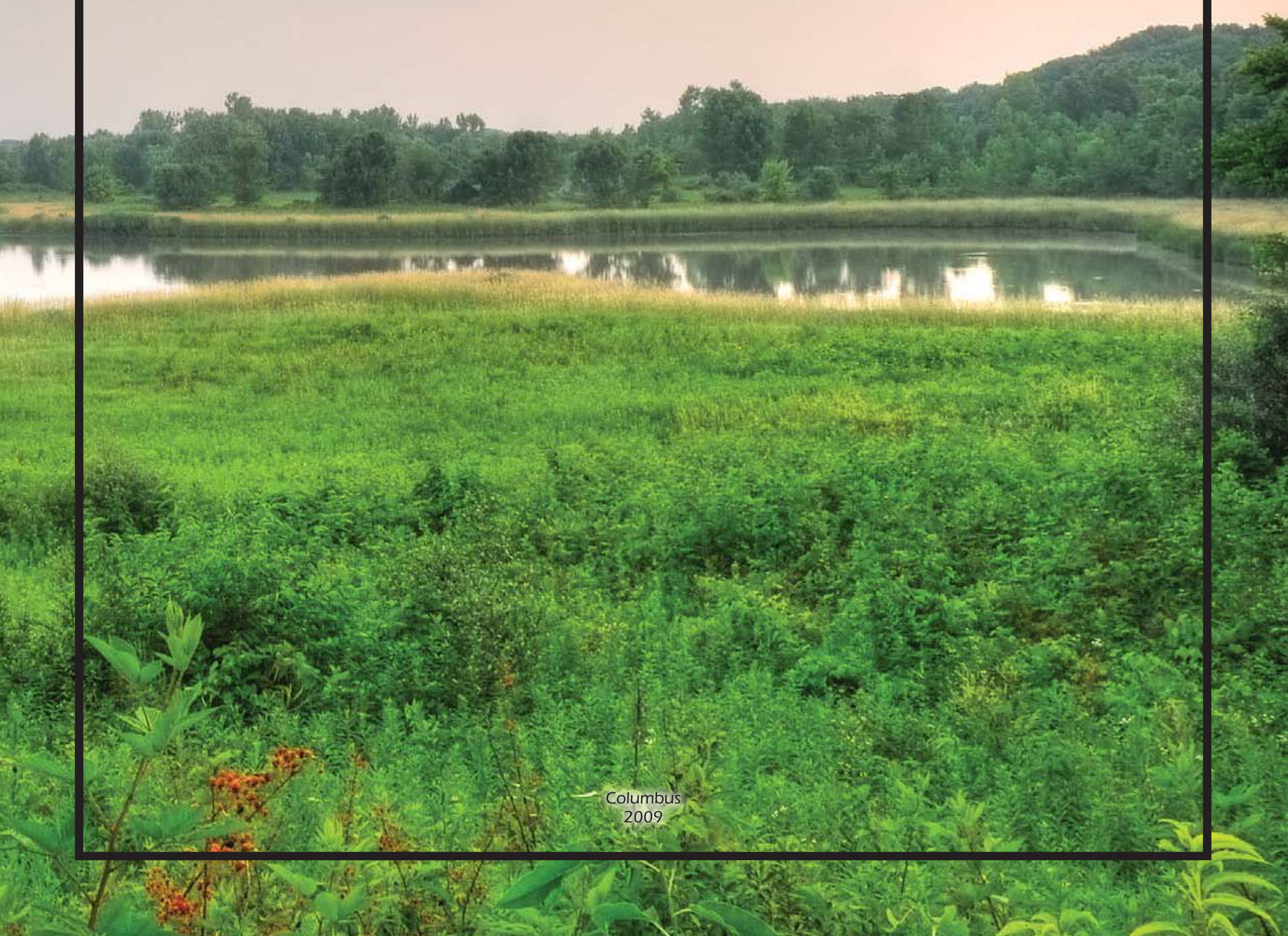
STATE OF OHIO
Ted Strickland, Governor
DEPARTMENT OF NATURAL RESOURCES
Sean D. Logan, Director
DIVISION OF GEOLOGICAL SURVEY
Lawrence H. Wickstrom, Chief

Information Circular No. 62

A REINTERPRETATION OF THE GLACIAL GEOLOGY AND AN ASSESSMENT OF THE LITHOLOGY OF GLACIAL SEDIMENTS IN THE AREA OF STAGE'S POND NATURE PRESERVE, ASHVILLE, OHIO

by
Erik R. Venteris and Glenn E. Larsen



Columbus
2009

DIVISION OF GEOLOGICAL SURVEY
2045 MORSE RD., BLDG. C-1
COLUMBUS, OHIO 43229-6693
(614) 265-6576
(614) 447-1918 (FAX)
e-mail: geo.survey@dnr.state.oh.us
World Wide Web: <http://www.ohiodnr.com/geosurvey/>

STATE OF OHIO
Ted Strickland, Governor
DEPARTMENT OF NATURAL RESOURCES
Sean D. Logan, Director
DIVISION OF GEOLOGICAL SURVEY
Lawrence H. Wickstrom, Chief

Information Circular No. 62

A REINTERPRETATION OF THE GLACIAL GEOLOGY AND AN ASSESSMENT OF THE LITHOLOGY OF GLACIAL SEDIMENTS IN THE AREA OF STAGE'S POND NATURE PRESERVE, ASHVILLE, OHIO

by

Erik R. Venteris and Glenn E. Larsen

Columbus
2009

Typesetting and layout: Lisa Van Doren

Cover illustration: A view of Stage's Pond State Nature Preserve.
Photo by Lisa Van Doren.

CONTENTS

FIGURES

TABLE

BLANK PAGE

A REINTERPRETATION OF THE GLACIAL GEOLOGY AND AN ASSESSMENT OF THE LITHOLOGY OF GLACIAL SEDIMENTS IN THE AREA OF STAGE'S POND NATURE PRESERVE, ASHVILLE, OHIO

by

Erik R. Venteris and Glenn E. Larsen

ABSTRACT

The glacial sediments in the vicinity of Stage's Pond were characterized and interpreted as part of an effort to assess the potential impact of a recently installed, nearby water supply well. A series of detailed soil borings and public water well records were analyzed and interpreted to determine if the geologic materials between the pond and the supply well to the southwest were porous enough to allow water flow between them. The depression that the pond occupies is approximately 110-feet deep and is filled with 70 feet of semi-permeable organic deposits interbedded with silts and clays. The generalized stratigraphy around the pond consists of approximately 10 to 35 feet of till, which overlies an ice contact deposit that is up to 200 feet thick. The bulk of the pond's depression is in contact with this lower unit, which contains a large proportion of high permeability lithologies (sands and gravels) ranging from 30 to 60 percent. Water well records from the area indicate that the ice contact deposit transitions to a higher proportion of sand and gravel to the west of the pond with 50 to 90 percent sand and gravel lithologies. Most of the few available borings deeper than 60 feet encountered permeable sediments. Due to the presence of semi-permeable sediments in the pond and the surrounding permeable sediments, hydrologic connectivity between the pond and supply well cannot be ruled out. In addition, the upper till layer was not compatible with the common interpretation of the pond as a kettle lake formed by the deposition of sand and gravels around a block of ice. Rather, the stratigraphic evidence was more compatible with the interpretation that the depression is a moulin scar formed during the final phases of disintegration and retreat of the last Wisconsinan ice sheet. The manner of formation of the pond is significant, as this new interpretation makes the presence of impermeable till at the bottom of the pond unlikely.

INTRODUCTION

Stage's Pond State Nature Preserve (39° 40' 27" N, 82° 56' 15" W) is a 178-acre preserve located near Ashville, Ohio, that is maintained by the Ohio Department of Natural Resources, Division of Natural Areas and Preserves. The central feature of the property is Stage's Pond (fig. 1), a 64-acre closed depression with a typical water depth of 10 feet (the water depth of the pond is variable, ranging from 0 feet to water levels where both ponds are connected, depending on climatic conditions). This feature provides a unique wetland habitat, and the preserve is used for wildlife-oriented scientific studies and recreation.

The Earnhart Hill Regional Water and Sewer District installed a one million gallon per day water supply well (PW-1, fig. 1) to a depth of 100 feet to support residential and commercial development. The well is located approximately 2,000 feet to the southwest of Stage's Pond. A key question is what potential impact, if any, the well will have on the hydrologic balance of the pond. The central issue is the potential for water flow from the pond to the well. Two conditions must be met for this to occur. First, the water table at Stage's Pond must be higher in elevation than that of the supply well, creating a gradient in hydraulic head. Water table measurements by Bennett and Williams Environmental Consultants, Inc. (2001 and 2007) show levels within two feet before pumping, and drawdown from pump testing lowered the water table by 26 feet at PW-1. Secondly, the geologic materials (glacial sediments) must be porous and permeable along potential flow paths between the pond and the well. The presence of highly permeable sand and gravel bodies favors flow, whereas the presence of low permeability tills, clays, and silts disfavor flow. Further assessment of the impact of pumping on the local water table is beyond the scope of this contribution. Rather, the composition of the glacial sediments and their geometry (size and interconnectivity) are studied through the analysis and interpretation of soil borings (Bennett and Williams Environmental Consultants, Inc., 1999, 2001, and 2007) and water well records (ODNR Division of Water, 2008) to assess the potential of the sediments within and surrounding the pond to transmit water.

STUDY AREA

Stage's Pond is a closed basin formed on the Wisconsinan till plain in south-central Ohio (fig. 1). The depression is formed on the edge of a local escarpment, with the surface elevation generally being highest to the east and northeast and lower to the southwest. The depression is elongated with a northwest to southeast orientation and dimensions of 3,300 feet in length and 1,000 feet in width. The local relief of the basin (rim of depression to shoreline) is approximately 35 feet. The depth of the depression is poorly constrained: a soil boring near the center of the pond (Snyder, Shane, and Kapp, 1991) penetrated at least 67 feet of organic-rich material and encountered gravelly sediment at the bottom of the boring. The total catchment area of the pond (calculated from a custom digital elevation model made for the site) is 358 acres and is covered by a mix of forest, agricultural, and wetland land cover types.

The pond was formed by glacial processes during the retreat of the last great ice sheet roughly 16,000 years

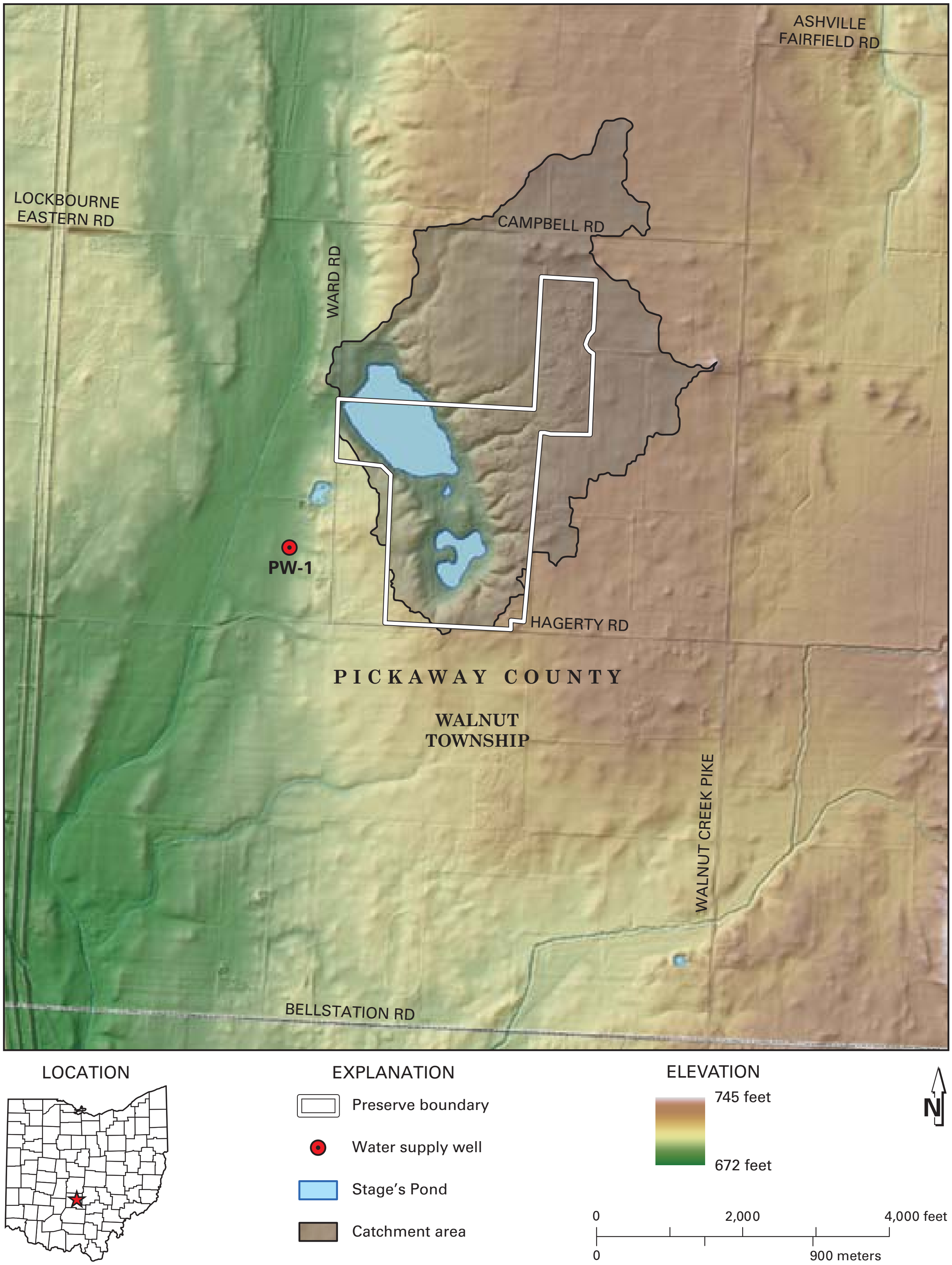


FIGURE 1.—Map showing the location of Stage's Pond and the supply well (PW-1) on a Digital Elevation Model (DEM) based on LIDAR data collected in 2006 by the Ohio Geographically Referenced Information Program's Ohio Statewide Imagery Program. The catchment area was calculated from this DEM using the hydrologic analysis tools in ArcGIS Spatial Analyst software by Environmental Systems Research Institute, Inc. (ESRI, 2006).

ago (T. Lowell, oral commun., 2008). The depression is typically interpreted as a glacial kettle formed by outwash sedimentation around a massive chunk of glacier ice, which subsequently melted away (Hansen, 1997). After the glacier retreated, the depression remained flooded, and a mixture of organic matter and mineral sediment (silt and clay) accumulated. The organic matter was dated using ^{14}C techniques; the oldest deposits were dated at 12,000 years old (L. Shane and M. Howes, written commun., 1991).

The geologic deposits underlying the pond are glacial sediments that range in thickness from 75 to nearly 200 feet (fig. 2). As interpreted in this contribution, the general stratigraphy is a thin till layer (≈20 feet) that overlies a complex ice contact deposit. These sediments overlie bedrock composed of Devonian-age shale (Slucher and others, 2006). The thickness of drift in the immediate area of the pond is only partially known, as there are no local penetrations to bedrock. The thickness of the drift is estimated from a combination of rock penetrations in the surrounding area, depth to bedrock estimates from seismic refraction (ODNR Division of Water, 1965), and minimum thickness estimates from local water wells and borings collected for this study. The current drift thickness map is based on a version of the bedrock topography (Shrake, 1995) that has been revised to include information from the Bennett and Williams borings (1999, 2001, and 2007). The drift in the immediate area is thickest along a north-south axis, which includes the pond area. The drift thins to the east as the bedrock surface rises and to the west due to erosion associated with the present Scioto Valley. The lithologic composition of materials in this drift layer is the main issue addressed in this study.

METHODOLOGY: PRESENTATION AND STATISTICAL ANALYSIS OF AVAILABLE BORING DATA

Soil boring records are the primary source of information on the subsurface geology surrounding Stage's Pond. There are two main sources of this information. A series of six deep boreholes (fig. 2), in addition to the production well, were drilled near the pond by Bennett and Williams Environmental Consultants, Inc. (1999, 2001, and 2007). For each of these borings, standard penetration tests were conducted and the lithology was described in detail. In addition, there are public records from water wells drilled in the area (ODNR Division of Water, 2008). These well records contain basic lithologic and color descriptions filed by private water well drilling companies. The interpretation of such records must be conducted with care (Venteris, 2006 and 2007), but they are a valuable resource because they are the most spatially dense and continuous data set available.

The seven detailed borings were prepared for interpretation by entering the records into a database and constructing a cross section using geographic information system (GIS) tools (fig. 3). The small number of wells of this type limits the value of statistical analysis with this dataset. In contrast, a statistical approach to interpretation was used for the public water well records. Interpretation inconsistencies and errors (especially in location) affect the reliability of any individual well (Venteris, 2006 and 2007). However, the strength of water well records is that they are typically available in large numbers. Statistical techniques can be used on groups of water wells to reduce outliers and expose common patterns in lithology.

A total of 107 water wells in the area surrounding Stage's Pond were selected for analysis. Wells approximately 2.5 miles north and south and 1 mile east and west of the PW-1 well were selected (fig. 4). Well selection was restricted in the east and west directions to exclude those in the main alluvial valley of the Scioto River (west) and the thin drift overlying bedrock to the east. Initial observations of well records suggested that the wells to the west contained more sand and gravel at depth than those surrounding the pond and to the east. Accordingly, the data were divided into two groups (fig. 4) for further analysis.

The original water well database was processed and reformatted to allow the information to be generalized and summary statistics calculated. Initially, the lithologic information in the original water well database had to be simplified. The original water well records contain up to 184 unique lithologic types. For most lithologic studies, these records must have non-geologic descriptions removed (e.g., fill, bricks, asphalt) and be converted to a more generalized model of lithology. Using database techniques, the lithology types from the original records were grouped into eight simple categories: clay, silt, sand, sand and gravel, till, bedrock, organic, and soil. A FORTRAN program was used to discretize the lithologic information into one-foot intervals. Each lithology layer in a given well is recorded as the depth to the bottom of each layer. The depths are recorded to the nearest foot, so each original record is split into one-foot increments to facilitate cross comparisons between wells.

Summary statistics for each of the two well groups were generated using custom software written in FORTRAN. The software calculates the proportion of each lithologic group for each one-foot depth interval. Summary statistics can be generated for any grouping of wells defined by the user (in this case the well groupings shown in figure 4). For this study, we are mainly interested in the proportion of facies that easily transmit water to those that do not. *Hydrofacies* (Ritzi, 2000) have been shown to serve as a good proxy for detailed measurements of hydraulic conductivity. For this work, clay, silt, and till lithologies are grouped together as impermeable facies, and the remaining lithologies are considered permeable (bedrock was not reached in any of the wells). The proportion of impermeable hydrofacies and their relationship with depth is presented in figure 5. In addition, the variability in lithology (using eight lithologies) between the wells for each depth interval was evaluated using Shannon's (1948) entropy

$$H = -\sum_{i=1}^{n} p_i \ln p_i \qquad (1)$$

where p_i is the proportion of each lithology. Small entropy values indicate consistent lithologies between the wells and

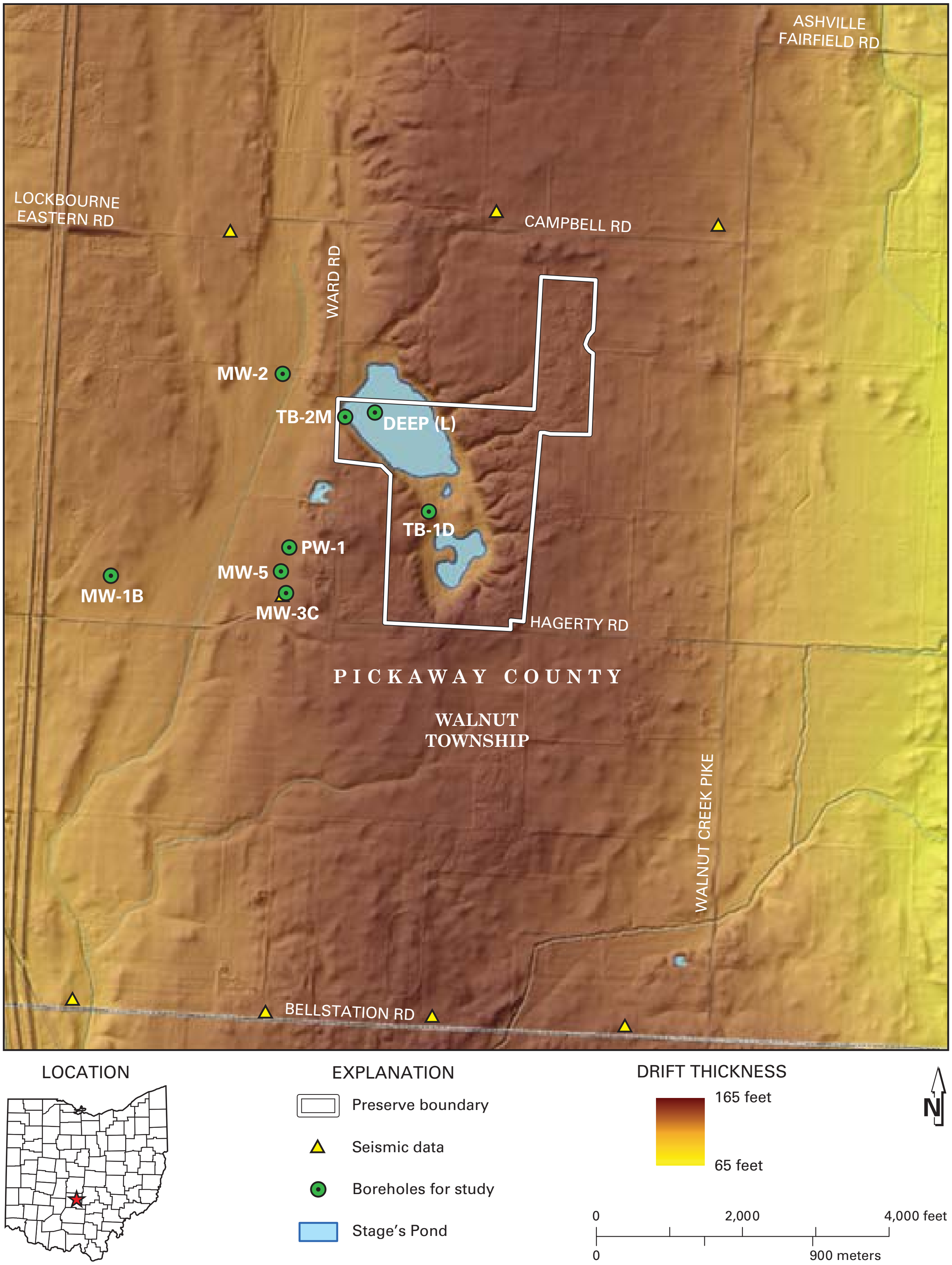


FIGURE 2.—Map of the thickness of drift in the vicinity of Stage's Pond. The location of water wells in the immediate area, seismic shot points from the ODNR Division of Water (1965), and detailed borings (Bennett and Williams Environmental Consultants, Inc., 1999, 2001, and 2007) are also shown.

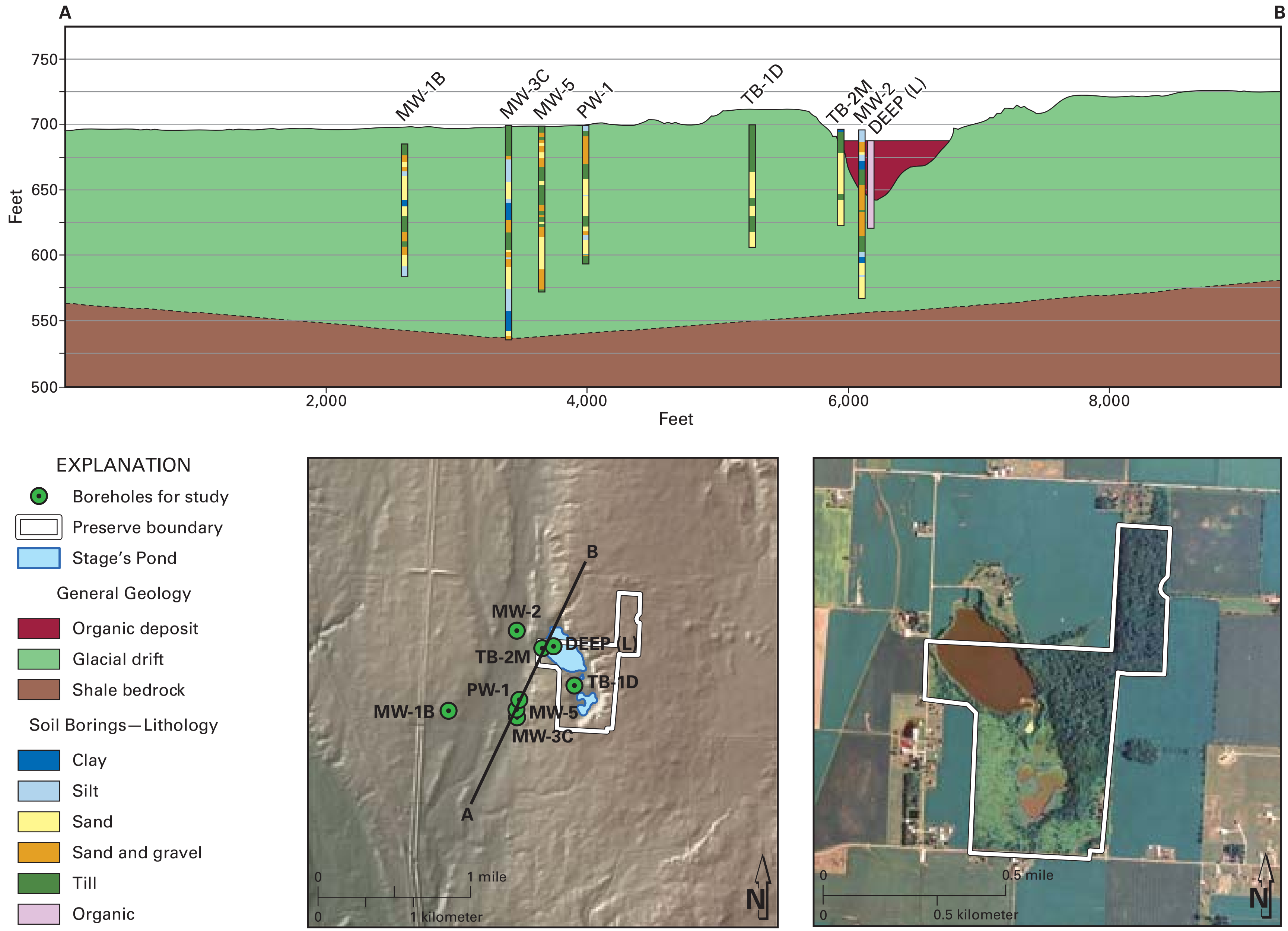


FIGURE 3.—Cross section showing the thickness of drift along a SW to NE profile and the lithologic records of the deep soil borings collected by Bennett and Williams Environmental Consultants, Inc. (1999, 2001, and 2007) for the Stage's Pond area. Borings are projected from a distance to the plane of the cross section and so may not match the elevations of the geologic surfaces exactly.

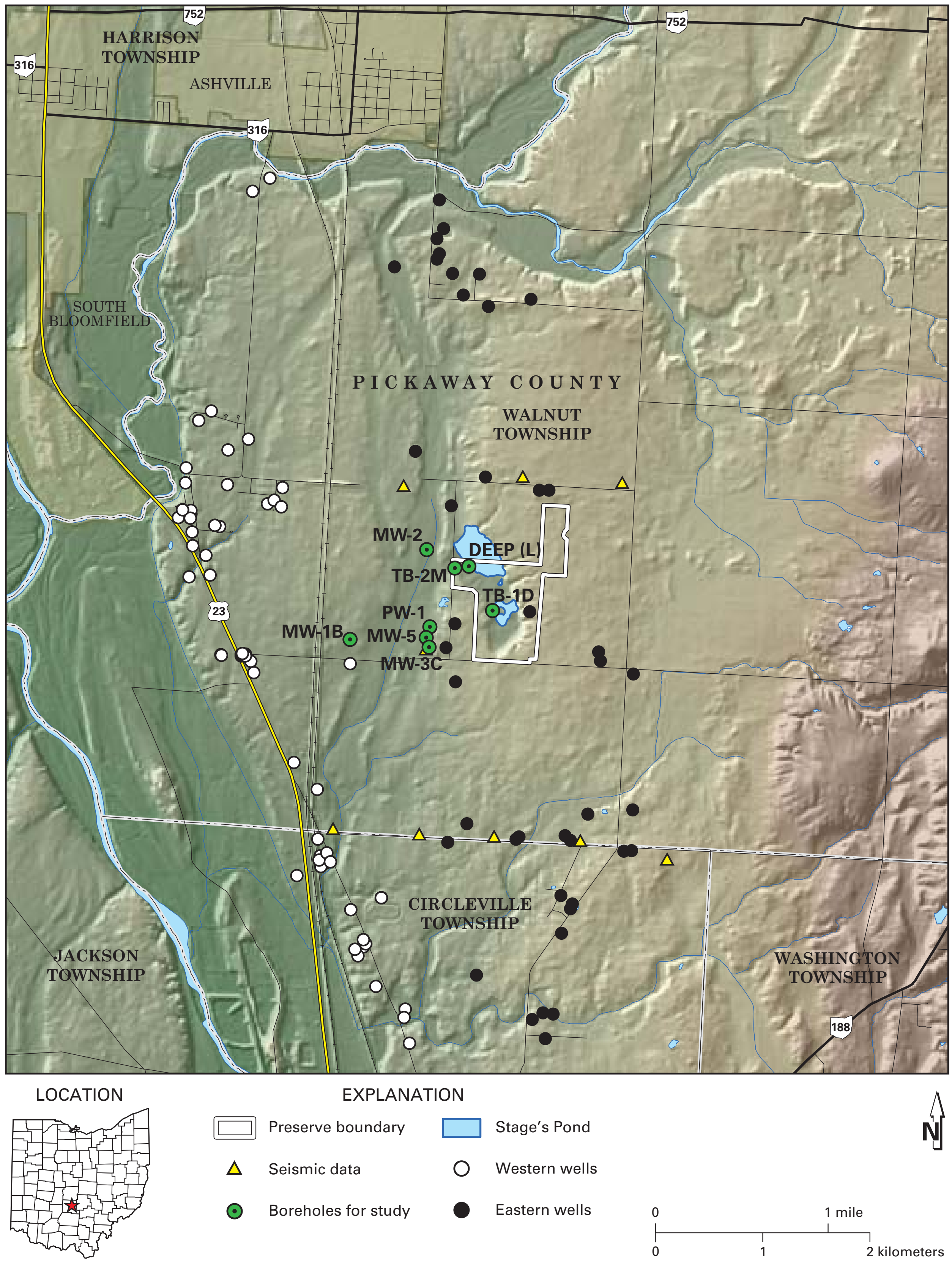


FIGURE 4.—Shaded relief map showing the locations of water wells in the vicinity of Stage's Pond. The eastern (filled dot) and western (open dot) groups of wells are superimposed on the map.

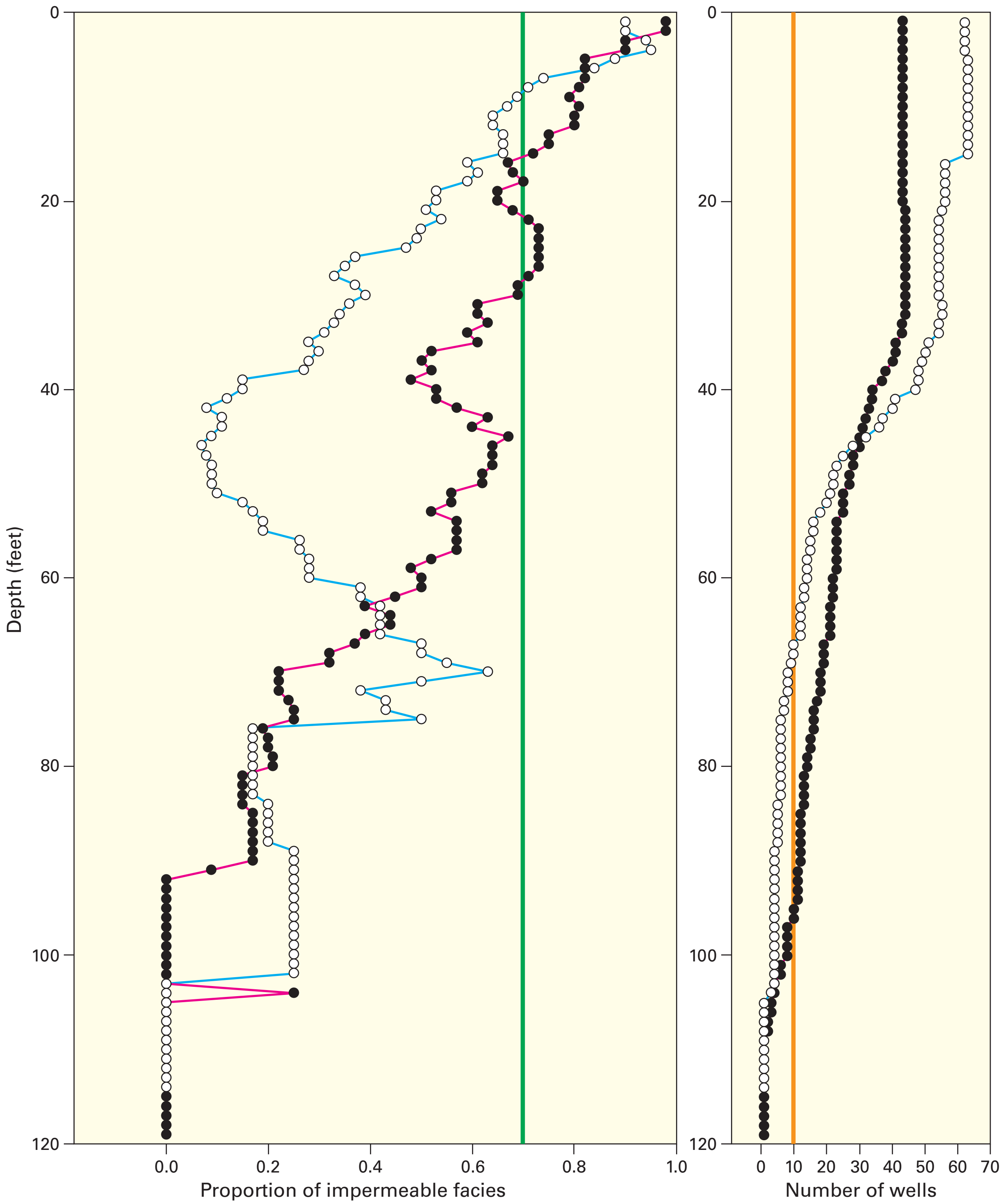


FIGURE 5.—Plot showing the proportion of impermeable facies in the Stage's Pond area with depth for the eastern (filled dot) and western (open dot) well groups (left) and the number of wells at each depth interval (right). The green line (0.69) shows the threshold for interconnection of sand bodies (flow pathways). Proportions of facies higher than this threshold will likely prevent significant movement (percolation) of water. The orange line indicates where there are less than 10 wells.

large values indicate that many different lithologies were recorded for the depth interval. Entropy values with depth are presented in figure 6.

DISCUSSION

Geologic interpretation

The lithologic records contained in the Bennett and Williams borings (1999, 2001, and 2007; fig. 3) provide insight into the glacial geology of the Stage's Pond area. A till layer lies at the surface in the area surrounding the pond and ranges in thickness from 9 to 35 feet. The till layer does not extend into the pond itself, as borings into the organic deposit bottomed into sand and gravel, although no sample was recovered (L.C.K. Shane, written commun., 2006). The presence of this till layer is at odds with the interpretation of Stage's Pond as a traditional kettle lake. The common interpretation for the formation of Stage's Pond is that a large block of ice was left behind as the main body of glacier ice retreated. Glaciofluvial sediments then deposited around the ice block, and when it melted a depression was left behind. However, the superposition of the till layer over the lower ice contact complex excludes this interpretation. If the depression were formed by deposition around a block of ice, the till must have been deposited later and should be present in the bottom of the depression. In addition, it is likely that the depression would have been smoothed over if the till represented a re-advance of the ice sheet. Finally, there is some evidence that the upper till layer and underlying ice contact deposits are separated in time. A piece of wood was found at 115 feet down in boring MW-3C that was dated to 22,000 years old (Bennett and Williams Environmental Consultants, Inc., 2001), which is at least 6,000 years older than the upper till layer.

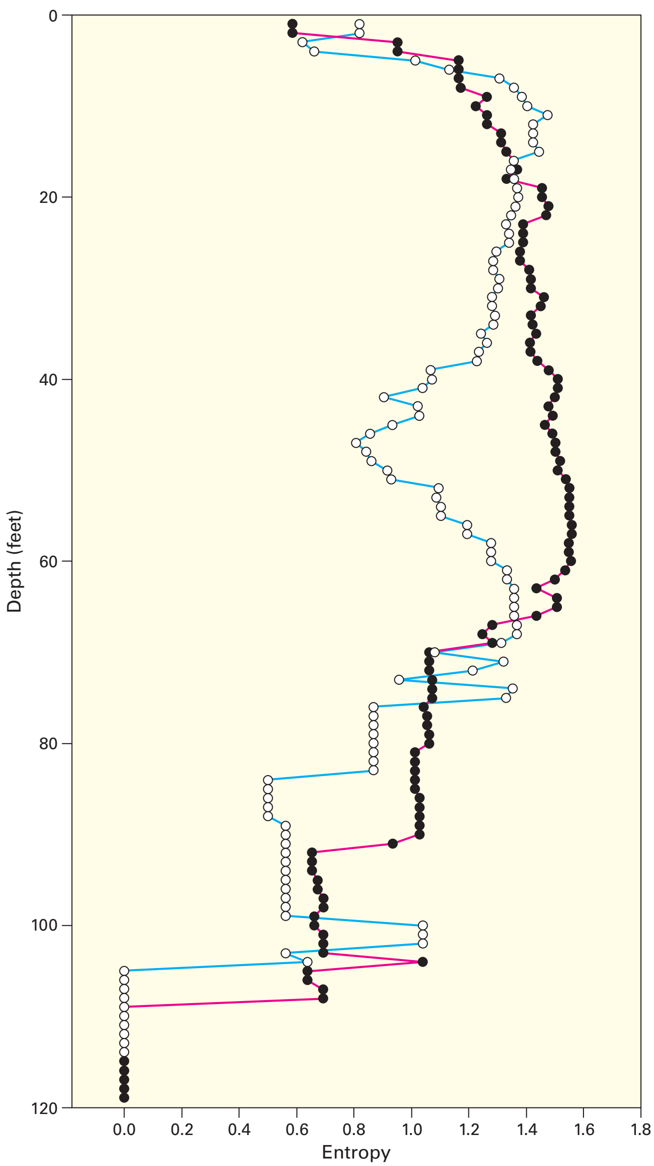


FIGURE 6.—Plot showing the relationship between entropy and depth of wells in the Stage's Pond area. The open dots are for the western well group and the filled dots are for the eastern well group.

An alternative interpretation that is more compatible with the stratigraphic record is that the depression is an erosional scar left by flowing glacial melt waters during the late stages of the Wisconsinan ice sheet. By this interpretation, the ice contact complex and much of the till was deposited before the depression formed. These layers were then eroded by an energetic flow of water, most likely in the form of a moulin (a vertical shaft melted through the glacier by meltwater), leaving behind a depression (fig. 7). The survival of the depression indicates that ice flow had largely ceased during the formation of this feature (ice stagnation and disintegration was well underway). Other closed depressions similar in morphology to Stage's Pond have been interpreted as moulin scars (Ehlers, 1996). The elongated nature of the depression also is compatible with this interpretation, as it could be produced by the transport of the moulin southward with the flow of glacier ice or northward migration due to melting of the shaft with continued water flow.

The sediments below the uppermost till layer in the area are very complex, with alternating layers of sand, sand and gravel, lacustrine silts and clays, and till. The number, type, thickness, and depth of the lithologic layers show little consistency between the wells. Whereas there are occasional similarities (e.g., the deep sand layers in TB-1D and TB-2M), the boring records alone are insufficient to determine which layers in an individual well represent local lenses and which can be traced from well to well as contiguous stratigraphic layers. There are a myriad of layer models one could apply to this data set and little scientific justification to choose one over another. The records are best interpreted as a facies assemblage characteristic of an ice contact deposit. The fluvial, lacustrine, and till sediments are interpreted as being deposited at the same time in a sub-ice environment containing melt water channels in the ice and soft sediment (Walder and Fowler, 1994). The type of sediment deposited depends on the presence or absence of melt water channels

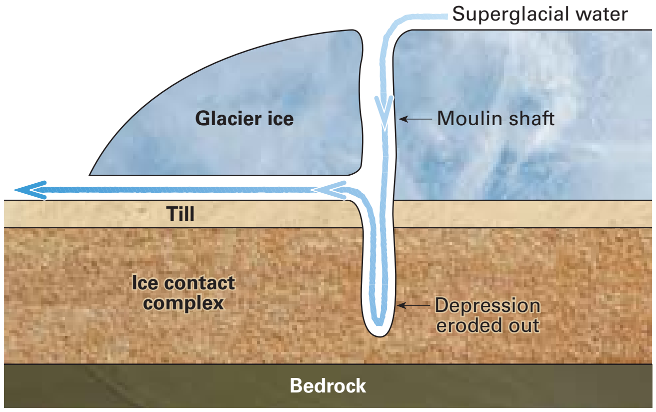


FIGURE 7.—Conceptual diagram illustrating the proposed mechanism for the formation of Stage's Pond by a moulin.

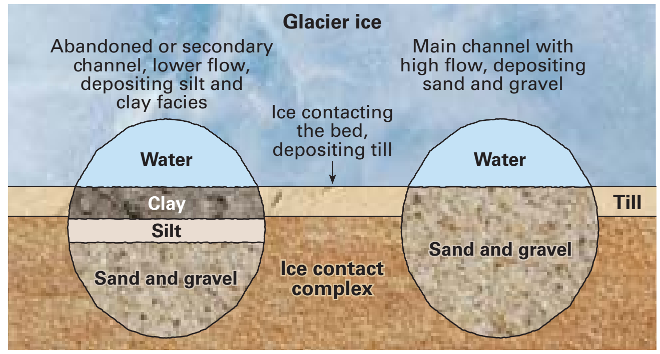


FIGURE 8.—Conceptual diagram illustrating the contemporaneous deposition of the wide range of lithologies found below the till layer. Till is deposited where ice contacts the bed, whereas other lithologies are deposited in subglacial water channels with varying stream competency.

and the velocity of the water flowing in them (fig. 8). The lateral migration and reorganization of these drainage channels over time produces the complexity in the sediment record. The model explains the complex lithologic patterns apparent in the well records without the need for multiple advances and retreats of the ice sheet, as would be required with an interpretation based on subaerial deposition.

Analysis of the water well records provides insight into the extent of the ice contact deposits. All wells show a high proportion of impermeable facies in the surface due to the uppermost till layer (fig. 5). However, there is a significant change in character in the deposits at depth. The eastern group of wells has a large proportion of impermeable facies over the depth interval of 20 to 60 feet. In addition, the entropy of the sediments in the eastern group is much higher than the western group over this interval (fig. 6). The variability in the sediments in the eastern portion, including those underlying Stage's Pond, are consistent with the ice contact interpretation. In contrast, the sediments below the till to the west are more uniform sands and gravels and are interpreted as glacial outwash. Data are presented below 60 feet, but there are a small number of wells that penetrate beyond this depth. With the exception of an increase in impermeable facies for the western group at approximately 70 feet in depth (fig. 5) and some deep clays and silts noted in the detailed borings (fig. 3), the majority of recorded lithologies located below 60 feet in depth are permeable sands and gravels.

Geologic potential for water flow

Whereas the seven detailed borings provide a basis for interpreting the geologic history and materials of the site, the complexity of their sedimentary records makes the objective assessment of hydrologic connectivity difficult. Arbitrarily, stratigraphic layer models could be drawn that show connection or disconnection. The lateral connections between the lithologic layers are unknown. An objective means of evaluating the potential for flow is needed.

Combining the water well information statistically minimizes the impact of errors and uncertainties from individual water wells but sacrifices spatial specificity. The likelihood of well-connected, permeable facies is evaluated using the hydrofacies proportions from the water well records. The interconnectivity for permeable facies within and between geologic bodies (percolation) has been studied by past workers using mathematical analysis (Stauffer and Aharony, 1994) and stochastic simulation (Guin and Ritzi, 2008). The results from these studies show that proportions of permeable facies greater than 30 percent will allow flow. For the area around Stage's Pond, only the upper till layer has a high enough proportion of impermeable material to prevent flow (fig. 5). Aside from a possible low permeability zone approximately 50 feet in depth, the proportion of permeable facies increases with depth to proportions of permeability greatly in excess of critical percolation values (fig. 5).

Finally, the pond sediments must also allow flow for a hydraulic connection. Although more detailed studies are required for a definitive assessment, an existing core can be used for a preliminary evaluation of this issue. Shane and others (2001) collected a core from the pond surface to the bottom near the center of the main pond. A steady decrease in organic matter with depth was noted: It ranged from approximately 70 percent at the surface to 25 percent near the base. The sediments in the pond meet the taxonomic criteria for classification as an organic soil (histosol; Soil Survey Staff, 1999); the upper 32 inches are more than 50 percent organic matter. Snyder and others (1991) measured the organic matter content using loss on ignition for a 30-foot deep core. Organic matter (dry weight) ranged from 37 to 60 percent. Laboratory measurements for the Deep (L) core (fig. 2) were conducted for three depth intervals (Bennett and Williams Environmental Consultants, Inc., unpub. data; table 1). In general, the samples from the pond have low bulk densities and high organic matter and water contents. From previous studies, the saturated hydraulic conductivities for organic rich soils are highly variable, ranging from 2,362

TABLE 1.—*Summary of laboratory analysis for samples taken from the Deep (L) core at Stage's Pond. Saturated hydraulic conductivities (K_{sat}) are estimated from figure 3.5 in Parent and Ilnicki (2002).*

Depth Range (ft)	Sand and Gravel (%)	Silt and Clay (%)	Organic Matter (%)	Water content	Bulk Density lbs ft^{-3}	Upper K_{sat} Estimate (inch day^{-1})	Lower K_{sat} Estimate (inch day^{-1})
22.3–25.1	34.7	21.3	44	424.8	12.6	0.43	0.12
42.2–44.95	28.8	30	41.2	380.7	14.3	0.39	0.08
64.5–66.9	22.5	60	17.4	187.4	25.9	<0.1	<0.1

inches day^{-1} for slightly decomposed examples to 0.0024 inches day^{-1} for highly decomposed and compacted organic deposits (Parent and Ilnicki, 2002). A range of conductivities for Stage's Pond were estimated based on an empirical relationship between bulk density and saturated conductivity derived by past workers (Parent and Ilnicki, 2002). Estimated hydraulic conductivities range from 0.11 to 0.43 inches day^{-1} at 20 feet in depth and decrease steadily with the increase in bulk density (and clay) with depth (table 1). Therefore, the organic sediments at the top of the ice contact deposit to at least 40 feet in depth are semipervious. For comparison, the maximum hydraulic conductivity for clay is approximately 0.003 inches day^{-1}. The upper 20 feet of the pond likely has higher conductivities than the measured samples due to lower bulk density and larger organic matter content (Shane and others, 2001).

CONCLUSIONS

The geology surrounding Stage's Pond is best characterized as a thin till deposit overlaying an ice contact deposit containing significant amounts of sand and gravel. The lower deposit has a high potential to transmit water as illustrated by this study and by pumping tests conducted by Bennett and Williams Environmental Consultants, Inc. (2001). Both the pond and the supply well to the southwest penetrate into this ice contact deposit. Boring observations and the interpretation of the pond as a moulin scar argue against the presence of a confining layer such as till at the bottom of the pond. Therefore, the ability of the pond sediments to prevent the downward flow of water is critical to maintaining the hydrologic balance of the pond. The initial evaluation of the pond sediments suggests that they are semipermeable and therefore further study is warranted.

ACKNOWLEDGMENTS

This work was partially supported by the Central Great Lakes Geologic Mapping Coalition, United States Geological Survey Cooperative Agreement No. 04ERAG0061. We thank the Ohio Department of Natural Resources, Division of Natural Areas and Preserves for allowing us to access the Stage's Pond property. In addition, we thank Carrie Jennings and Amy Myrbo of the Minnesota Geological Survey for providing information on the borings conducted in the pond.

REFERENCES CITED

Bennett & Williams Environmental Consultants, Inc., 1999, Results of test boring program wellfield siting study: report presented to Earnhart Hill Regional Water and Sewer District (unpub.).

Bennett & Williams Environmental Consultants, Inc., 2001, Aquifer testing results—Noecker property: report presented to Earnhart Hill Regional Water and Sewer District (unpub.).

Bennett & Williams Environmental Consultants, Inc., 2007, Results of test pumping at Stage's Pond: report presented to Earnhart Hill Regional Water and Sewer District and Ohio Department of Natural Resources (unpub.).

Ehlers, Jurgen, 1996, Quaternary and glacial geology: New York, John Wiley & Sons, 578 p.

ESRI, 2006, ArcGIS Spatial Analyst 9.2: [Redlands, Calif.], Environmental Systems Research Institute, Inc., information at <http://www.esri.com/software/arcgis/extensions/spatialanalyst/index.html>.

Guin, A. and Ritzi, R.W., Jr., 2008, Studying the effect of correlation and finite-domain size on spatial continuity of permeable sediments: Geophysical Research Letters, v. 35, L10402.

Hansen, M.C., 1997 (rev.), The Ice Age in Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Educational Leaflet 7, 5 p.

ODNR Division of Water, 1965, Groundwater for Industry in the Scioto River Valley: Columbus, Ohio Department of Natural Resources, Division of Water, 29 p.

ODNR Division of Water, 2008, Water well log report: Ohio Department of Natural Resources, Division of Water, last accessed January 31, 2008, at <http://www.dnr.state.oh.us/water/>.

Parent, L.E. and Ilnicki, P., 2002, Organic soils and peat materials for sustainable agriculture: Boca Raton, Fla., CRC Press, 205 p., fig 3.5.

Ritzi, R.W., 2000, Behavior of indicator variograms and transition probabilities in relation to the variance in lengths of hydrofacies: Water Resources Research, v. 36, no. 11, p. 3375–3381.

Shane, L.C.K., Snyder, G.G, and Anderson, K.H., 2001, Holocene vegetation and climate changes in the Ohio region, *in* Prufer, O.H., Pedde, S.E., Meindl, R.S., eds., Archaic transitions in Ohio and Kentucky prehistory: Kent, Ohio, Kent State University Press, p. 11–55.

Shannon, C.E., 1948, A mathematical theory of communication: Bell System Technical Journal, v. 27, p. 379–423 and 623–656.

Shrake, D.L., 1995, Bedrock topography of the Ashville, Ohio, quadrangle: Ohio Department of Natural Resources, Division of Geological Survey Open-File Map BT-B3F8, scale 1:24,000.

Slucher, E.R., Swinford, E.M., Larsen, G.E., and others, with GIS production and cartography by Powers, D.M., 2006, Bedrock geologic map of Ohio: Columbus, Ohio Department of Natural Resources, Division of Geological Survey Map BG-1, scale 1:500,000.

Snyder, G.G., Shane L.C.K., and Kapp, R.O., 1991, Palynological studies associated with the Mound City Group National Monument, Chillicothe, Ohio: Final Report to the National Park Service, fulfillment of contract issued in 1988, 99 p.

Soil Survey Staff, 1999, Soil taxonomy, a basic system of soil classification for making and interpreting soil surveys (2d ed.): Washington, D.C., U.S. Department of Agriculture, Natural Resources Conservation Service Agricultural Handbook Number 436, p. 473.

Stauffer, Dietrich, and Aharony, Amnon, 1994, Introduction to percolation theory (2d ed.): Philadelphia, Taylor and Francis, 181 p.

Venteris, E.R., 2006, Qualitative and quantitative 3D modeling of surficial materials at multiple scales, *in* Digital Mapping Techniques '06—Workshop Proceedings, Columbus, Ohio, June 11–14, 2006: U.S. Geological Survey Open-File Report 2007-1285, p. 129-149, last accessed June 30, 2009, at <http://pubs.usgs.gov/of/2007/1285/pdf/Venteris.pdf>.

Venteris, E.R., 2007, Three-dimensional modeling of glacial sediments using public water-well data records—an integration of interpretive and geostatistical approaches: Geosphere, v. 3, p. 456–468.

Walder, J.S., and Fowler, A., 1994, Channelized subglacial drainage over a deformable bed: Journal of Glaciology, v. 40, p. 3–15.

BLANK PAGE

Venteris and Larsen—A REINTERPRETATION OF THE GLACIAL GEOLOGY AND AN ASSESSMENT OF THE LITHOLOGY OF GLACIAL SEDIMENTS IN THE AREA OF STAGE'S POND NATURE PRESERVE, ASHVILLE, OHIO—Ohio Division of Geological Survey Information Circular No. 62

IC62